STATUS OF MINERAL RESOURCE INFORMATION FOR THE WARM SPRINGS INDIAN RESERVATION, OREGON

BY

G. W. Walker
U.S. Geological Survey

S. W. McNary
U.S. Bureau of Mines

Administrative Report BIA-26
1977

CONTENTS

SUMMARY AND CONCLUSIONS

The Warm Springs Indian Reservation is in an area of low mineral potential and, except for common construction materials such as perlite and building stone, no known commercial deposits are present within its boundaries. A small quarry produces limited quantities of dimension stone (tuff). Several varieties of agate and thunder eggs occur in the Mutton Mountains in the northeastern part of the reservation, which might support a small-scale semiprecious gem stone industry. Rock collecting by non-Indians is not permitted at this time.

The presence of both hot springs and young andesitic and basaltic volcanoes on the reservation indicates some potential for the development of geothermal energy. Both measured and computed temperatures of hot spring waters indicate there is little likelihood of an adequate heat source for the production of electrical energy under current technological constraints. However, there is potential for space heating beyond that currently used at Kah-Nee-Ta. Perhaps development of the resource could provide sufficient heat for a greenhouse or hydroponic enterprise.

INTRODUCTION

Purpose

This report was prepared for the U.S. Bureau of Indian Affairs by the U.S. Geological Survey and the U.S. Bureau of Mines under an agreement to compile and summarize available information on the geology, mineral resources, and potential for economic development of certain Indian lands. Sources of information included published and unpublished data, and personal communications. There was no field work.

Geography

The Warm Springs Indian Reservation, located about 60 air miles southeast of Portland, consists of 564,330 acres in Jefferson, Wasco, Marion, and Clackamas Counties in north-central Oregon (Figure 1). Of the total area, 480,196 acres are tribally owned, 84,118 acres are allotted, and 16 acres are government owned (U. S. Dept. of Commerce, 1974, p. 486). The reservation's dimensions are about 43 miles north-south and about 36 miles east-west. The tribal headquarters is at Warm Springs, 15 miles northwest of Madras on U.S. Highway 26 (Figure 1).

The western boundary of the reservation is along the crest of the High Cascades. Jefferson Creek, the Metolius River, and Lake Billy Chinook form the southern boundary. On the east, it is bounded by Lake Simtustus and the Deschutes River and on the north by the north-facing slopes of the Mutton Mountains, and the Laughlin Hills.

Altitudes range from 10,497 feet at Mount Jefferson on the western boundary to 1,580 feet at the Deschutes River below Round Butte Dam. The steep slopes of the Cascade Range give way to a more gentle rolling topography on the east. Stream valleys are U-shaped and most slopes near the crest and below 6,500 feet are forested. Eastward the topography consists of broad, gentle slopes incised by deep, steep-walled canyons. Here the vegetation is typical of a semi-arid climate with scattered juniper and sagebrush. All streams originate in the Cascade Mountains and drain eastward to the Deschutes River.

The reservation is semi-arid with an average annual precipitation of about 12 inches, except near Mount Jefferson where precipitation averages about 100 inches. Greatest precipitation occurs during November, December, and January. August is usually the driest month (Oregon State Water Resources Board, 1961, p. 70).

The reservation is easily accessible with U.S. Highway 197, a major north-south route through Oregon, passing along the eastern boundary. This highway services both Madras east of the reservation and Bend, about 60 miles to the south. Another major route, U.S. Highway 26, trends northwest-southeast across the reservation to Portland. The area is covered by an extensive network of unpaved roads.

Railroad, bus, and airlines also service the nearby area. A branch of the Burlington Northern railway (formerly Oregon Trunk Railroad) passes near the Deschutes River and provides freight service. Commercial bus service is available from Warm Springs and Madras. Bend has a municipal airport. Commercial air service also is available to Portland from Redmond.

Map Coverage

Topographic maps covering the Warm Springs Reservation are listed below and shown on Figure 2. These maps may be ordered from the U.S. Geological Survey, Denver, Colorado.

7 ½-minute quadrangles

Foreman Point	Warm Springs
Wapinitia	Eagle Butte
Maupin SW	Gateway
Dant	Metolius Bench
Hehe Butte	Seekseequa
Simnasho	Madras West
Mutton Mtn.	Fly Creek
Kaskela	Round Butte Dam
Potters Ponds	

15-minute quadrangles

Mt. Wilson
Breitenbush Hot Springs
Fort Butte
Mt. Jefferson
Whitewater River

30-minute quadrangles
(out-of-print)
Dufur
Madras

Acknowledgments

Special acknowledgment is made to Mr. Harlow Nasewytewa, Realty Officer, Bureau of Indian Affairs, Warm Springs Indian Agency, who supplied current data concerning the status of the mineral commodities on the reservation. Mr. Ralph Mason, Deputy Chief, Oregon Department of Mineral Industries, provided information about the Lady Frances perlite mine.

Brief examination of the hot springs on the reservation and evaluation of their potential for geothermal energy was made in 1973 by Norman S. MacLeod and Edward A. Sammel, both of the U.S. Geological Survey. The results of their brief study have been made available to the authors, for which we thank them. Also, special acknowledgment is made to Dr. Aaron C. Waters, Professor Emeritus, University of California at Santa Cruz, who kindly made available some unpublished geologic maps in areas west of Long. 121º30' W. in the Fort Butte and Whitewater River quadrangles.

PREVIOUS INVESTIGATIONS

The eastern and central parts of the Warm Springs Indian Reservation have been the subject of several regional studies leading principally to geologic maps. Only a small amount of descriptive information has been published on rock units in the area. The western part of the reservation, high in the Cascade Range, has received little attention and the limited geologic reconnaissance that has been done is largely unpublished. A few reports, which are mentioned below, discuss special features of the geology, of the water resources or chemical and physical characteristics of ground and surface waters, and of mineral resources within or near the reservation boundaries. Much of the basic geologic information on stratigraphy and structure of this region is the result of studies principally in areas to the east of the reservation (see Swanson, 1969, and his list of references) and one major study in the Western Cascades (Peck and others, 1964).

Some of the first systematic geologic mapping within the confines of the reservation was done in the 1920's and early 1930's by students from the University of Oregon and Oregon State College (now University) under the direction of Dr. E. T. Hodge. This work resulted in a published reconnaissance geologic map of a large area in north-central Oregon (Hodge, 1932) that included part of the reservation east of Long. 121º30' W. and a report on the geology of the region (Hodge, 1942). Another product of this work was a map, including brief text, of the geology of the Madras 30-minute quadrangle (Hodge, 1941). Wilkinson (1932) made a petrographic study of some of the rocks exposed in the Mutton Mountains, as a part of the investigations under Dr. Hodge's supervision.

At about the same time, Stearns (1931) reported on the geology and water resources of a large region extending from about Lapine to Tygh Valley and from the Cascade crest to areas east of Prineville. A geologic map (Stearns, 1931, pl. 10) covers a part of the reservation near the confluence of Metolius and Deschutes Rivers. In addition to describing the geology of several dam sites on the Deschutes and Crooked Rivers, Stearns includes geologic information on the diatomite deposits at Terrebonne, several miles south of the reservation.

In conjunction with the preparation of a geologic map of Oregon west of the 121st meridian (Wells and Peck, 1961), reconnaissance geologic mapping was done in the Dufur and Madras 30-minute quadrangles and in selected areas to the west in the Cascade Range. This resulted in a geologic map of the Dufur quadrangle (Waters, 1968a), which includes that part of the reservation east of Long. 121º30' W. and north of the 45th parallel, and a revised and updated reconnaissance geologic map of the Madras 30-minute quadrangle (Waters, 1968b). The geology of a small part of the reservation near Lake Billy Chinook is included in a report on the geology of Cove Palisades State Park by Peterson and Groh (1970). An investigation by Walker, Greene, and Pattee (1966) of the mineral resources of the Mount Jefferson Primitive area obtained some data bearing on the mineral potential of the reservation, and on perlite deposits at the Lady Frances mine, just north of the reservation on the Deschutes River (Allen, 1946; Mason, 1951, p. 14; Wagner, 1969, p. 226-227).

Robison and Laenen (1976) recently completed a general study of the water resources of the reservation. Some detailed information was obtained on the composition and temperature of hot-spring waters (Mariner and others, 1974) and estimates of the minimum reservoir temperatures to be expected underground.

Isotopic ages of selected younger geologic units within and adjacent to the Warm Springs Indian Reservation have been published by Armstrong and others (1975).

GEOLOGY

Stratigraphy

General

The Warm Springs Indian Reservation includes a part of the High Cascades physiographic province and a part of the east-sloping piedmont that comprises the southwest margin of the Deschutes--Umatilla Plateau province. In common with adjacent parts of these provinces, the rocks of the reservation are predominantly of either volcanic extrusive origin or represent continental sedimentary deposits composed mainly of volcanic debris. Locally there are small intrusive masses of basalt, andesite, or rhyolite. The rocks range from Eocene to Holocene in age or from about 40 million years to a few thousand years. The oldest rocks, including those of the Clarno and John Day Formations, have been studied in considerable detail in areas several miles east of the reservation in and near the Ochoco Mountains (Waters and others, 1951; Swanson, 1969; Swanson and Robinson, 1968; Robinson, 1975). The next youngest group are distal parts of the Columbia River Basalt Group, an extensive sequence of basalt flows and related flow breccias exposed principally in areas northeast of the reservation along the Columbia River and its tributaries. Successively younger rocks include sediments and volcanic rocks of the Dalles Formation, extensive sheets of olivine basalt and more restricted andesite flows and breccias representing part of the volcanic rocks of the High Cascades (Thayer, 1936, 1937; Peck and others, 1964). Younger surficial deposits of alluvium and gravel, glacial moraines, and glacial outwash are also evident.

Distribution of the rock units within the Warm Springs Indian Reservation is shown on Figure 2 and their relative stratigraphic position in Figure 3.

Older Volcanic and Sedimentary Rocks

<u>General</u>.--Lower and middle Cenozoic volcanic and sedimentary rocks are exposed extensively in the northeast quarter of the reservation and more extensively in areas both east and west of the reservation. These rocks, which include parts of the Clarno and John Day Formations, are slightly to moderately altered and are structurally de-

formed; they correlate in part with "the volcanic rocks of the Western Cascades" (Peck and others, 1964, p. 7).

Clarno Formation.--The name Clarno Formation was originally assigned to a sequence of volcanic and volcaniclastic rocks exposed near Clarno on the John Day River (Merriam, 1901a, 1901b), about 40 miles east of Warm Springs. Rocks of this Eocene and lower Oligocene formation crop out extensively from Clarno to a few miles east of Madras where they project beneath younger rocks. They reappear in several areas in the northeast part of the reservation (Figure 3) mostly marginal to and northwest of the Mutton Mountains. The total thickness of the formation in and adjacent to the reservation or its distribution beneath younger volcanic and sedimentary rocks is unknown; presumably it underlies most of the reservation.

The Clarno Formation exposed on the reservation consists principally of altered (zeolitized and argillized) andesitic flows, flow breccias, and mudflows with local minor interbeds of tuff and tuffaceous siltstone. Several andesitic plugs that fill source vents for these flows and clastic rocks have been recognized on the Deschutes River, in Eagle Creek southwest of Frieda, and on hills about 2 miles north-northwest of Kah-Nee-Ta Hot Springs. A part of the Clarno Formation near Frieda, just north of the reservation, was described by Hodge (1941) to be about 2,000 feet thick and composed of interlayered light-colored rhyolite tuff, sandstone, shale, some agglomerate, and several basalt flows.

In many places, both on the reservation and elsewhere, the topmost layers of the Clarno Formation have been eroded and a distinctive weathering layer of soft, reddish residual clay and silt, generally referred to as saprolite, is developed.

John Day Formation.--An unconformity separates the Clarno Formation from the overlying Oligocene and lower Miocene John Day Formation, a sequence of volcanic and sedimentary rocks that are widely exposed throughout central Oregon. The John Day Formation was originally described from scattered exposures along the John Day River between Clarno and Picture Gorge (Merriam, 1901a, 1901b), 40 to 50 miles east of the reservation. It has been traced westward from the John Day River to areas a few miles east of Madras where it is buried by basalt flows of the Columbia River Basalt Group and the Dalles Formation (Waters, 1954; Peck, 1964; Swanson, 1969; Robinson, 1975). The formation reappears in the canyon of the Deschutes River and is exposed west of the river in the lower reaches of Tenino and Shitike Creeks and in the canyon of Warm Springs River below the junction of Mill and Beaver Creeks. Smaller outcrop areas of the formation are present at Hehe Butte and a little further to the southwest at Sidwalter Butte.

Within the reservation the John Day Formation consists predominantly of an interbedded sequence of light-colored air-fall and water-deposited ash, lapilli tuff, both welded and nonwelded ash-flow tuff, and rhyolitic flows. Local rhyolitic vents form plugs and domes. The maximum thickness of the sequence is about 2,000 feet in and near the reservation, but the thickness is highly variable.

Most of the rhyolite flows and domes are along the crest and upper slopes of the Mutton Mountains and on the ridge southwest of Kah-Nee-Ta Hot Springs, whereas the volcaniclastic and sedimentary rocks tend to form the lower, more easily eroded, slopes. Much of the fragmental material in the ash and tuff beds originally was rhyolitic glass, but commonly it has been altered to zeolites, clay minerals, opal, and other minerals.

<u>Basalt Porphyry</u>.--One small mass of basalt porphyry is exposed in the Deschutes River canyon at the east base of the Mutton Mountains. The porphyry intrudes rocks of the Clarno Formation, but it is not in contact with any of the younger rocks units of the area. Hence, it may be the same age as part of the Clarno Formation or it may be much younger.

Columbia River Basalt Group

Miocene and possibly lower Pliocene columnar jointed basalt flows and local thin interbeds of tuff and tuffaceous sandstone that represent part of the Columbia River Basalt Group unconformably overlie the John Day Formation in the northern and eastern parts of the Warm Springs Indian reservation. The flood basalts of the Group are part of one of the most extensive units in the Pacific Northwest, extending across much of eastern Washington, northeastern Oregon, and northwestern Idaho. Throughout this vast region the Group has been subdivided into several formations including the Yakima and Picture Gorge Basalts characterized by distinctive mineralogy and chemistry. According to Waters (1968b), distal parts of both Yakima and Picture Gorge Basalt have been recognized on the reservation. The flows are exposed on the Laughlin Hills in the northern part of the reservation, on plateaus of the eastern part of the reservation, and in Deschutes River Canyon south of Warm Springs. Some former outcrops of these flows are now covered by water impounded behind Pelton Dam on the Deschutes River (Figure 1).

According to Robison and Laenen (1976, p. 5), rocks of this unit "...consist of basalt flows which are dense, hard, and not easily eroded, but where sufficiently fractured it will transmit water readily. On the reservation, the basalt is generally less than 300 feet thick...."

Dalles Formation

Light-colored tuffaceous sedimentary rocks, with some interlayered flows of basalt and andesite, comprise the bulk of the Dalles Formation in and adjacent to the reservation. The formation, which originally was named for comparable rocks in areas north of the reservation near The Dalles, Oregon, locally rests unconformably on flows of the Columbia River Basalt Group and within the reservation also rests on both John Day and Clarno Formations. At various times these rocks also have been referred to informally in published reports as the Madras and Deschutes Formations. The most extensive exposures of the unit are in the drainage basin of Seekseequa Creek, and to the south along the canyon of the Metolius River. Smaller outcrop areas are present along Tenino and Shitike Creeks, and northward along the margins of Warm Springs River. A maximum thickness of about 1,000 feet is exposed in the walls of Seekseequa Creek Canyon;

the unit thins to the northeast and finally laps out on the older rocks in and adjacent to the Mutton Mountains.

According to Waters (1968b), the formation is composed chiefly of "...water-laid pumice-rich pyroclastic rocks, showing much crossbedding and channeling." It also contains numerous ash-fall deposits and less abundant welded and nonwelded tuffs. Basalt and andesite flows that are interbedded with the clastic rocks of the unit are generally too thin to be shown at the scale of the geologic map (Figure 3), but a few more extensive flows are delineated. Other, thinner, flows are shown by Waters (1968b).

The formation has been considered to be of both late Miocene and Pliocene age, with the latest published consensus indicating a Pliocene age (Newcomb, 1966). However, recently published potassium-argon dates indicate that both Pliocene and Miocene age rocks are probably present. A published potassium-argon date (Armstrong and others, 1975, sample locality 25) obtained on a sample of andesite flow, probably interstratified with the upper part of the unit, indicates an age of about 5.7 million years. The sample location is on the northeast wall of Whitewater River Canyon at an altitude of 3,100 feet, 0.7 miles northeast of the confluence of Whitewater and Metolius Rivers (44º40'38" N. lat.; 121º32'08" W. long.). Another potassium-argon date on an olivine basalt flow mapped as part of this unit (Waters, 1968b) and collected from the west wall of Deschutes River canyon 2.5 miles north of Round Butte Dam (44º38'22" N. lat.; 121º16'06" W. long.) indicates an age of about 15.9 m.y. (Armstrong and others, 1975). Perhaps this basalt flow may be older than the Dalles Formation and correlative with flows of the Columbia River Basalt Group which crop out nearby.

Younger Volcanic and Sedimentary Rocks

General.--Most of the central and western part of the reservation is underlain by flows and flow breccias of andesite, basaltic andesite, and basalt and volcaniclastic deposits that belong to upper Cenozoic sequence generally referred to as the volcanic rocks of the High Cascade Range. Although they are little known from areas within the reservation, they have been described in adjoining areas (Thayer, 1936, 1937; Williams, 1942, 1944, 1957; Peck and others, 1964).

In and near the reservation the volcanic rocks of the High Cascade locally can be divided into a lower unit dominated by olivine-bearing basalt flows in widespread sheets 10 to 20 feet thick, an upper unit of andesite and basaltic andesite flows that range in thickness from a few feet near vents to more than 100 feet on the flanks of the volcanoes and in intracanyon accumulations and a few local late andesite and basaltic flows and cones that are postglacial in age. This entire volcanic sequence is considered to be Pliocene to Holocene in age (Williams, 1957; Peck and others, 1964, p. 38). Only a few flows have been dated by potassium--argon methods (Armstrong and others, 1975, sample localities nos. 11, 12, and 13), all from the upper part of the flow sequence. Porphyritic basaltic andesite from two different localities on Bald Peter, in the southwestern part of the reservation, gave ages of 2.1 million years and one sample of intracanyon olivine-bearing basalt, collected on the north side of Jefferson Creek one mile upstream from the Metolius River, is 1.6 million years in age.

Olivine Basalt.--Thin flows of olivine basalt cap most of the plateau areas in the central and south-central parts of the reservation, including Schoolie Flat, Mill Creek Flat, and Tenino and Metolius Benches. Commonly the flows form clifflike rims on the margins of benches and plateaus. Throughout most of this area the flows rest discordantly on the Dalles Formation, but near Schoolie Flat northwest of Kah-Nee-Ta Hot Springs, the flows lap directly on both Clarno and John Day Formations. Both here and in adjoining areas geologic and isotopic data indicate that these olivine basalt flows are probably all of Pliocene age. Vents for these flows have not been recognized. Presumably they are buried under the younger overlying andesite and basalt flows and flow breccias that erupted from vents along the axis of the Cascades.

Andesite.--Stratigraphically and disconformably above the olivine basalt is a widespread unit (Ta) of flows, flow breccias, and mudflows of Pliocene and Pleistocene age that form the higher slopes ranging to the crest of the Cascades. The flows, breccias, and mudflows are composed predominantly of pyroxene andesite and olivine andesite.

Gravels.--In the central and west-central part of the reservation, particularly on Mill Creek Flat, extensive gravel beds occur stratigraphically above the andesite and basalt flows and breccias of the younger volcanic rocks. The gravels, which are more than 100 feet thick in places, are mostly well sorted and composed largely of andesite debris spread eastward by streams emerging from the Pliocene and Pleistocene volcanic piles of the High Cascades to the west. Waters (1968a, 1968b) considered the gravels to be of Pleistocene age, but some of these gravels may be as old as Pliocene (Robison and Laenen, 1975, p. 6 and pl. I).

Valley-Filling Basalt.--Following erosion of the deep canyons of the Deschutes and Metolius Rivers, basalt flows from vents outside the reservation partly refilled the river channels in late Pleistocene or Holocene time. Remnants of these thick intracanyon olivine basalt flows are present in isolated patches along the wall of Metolius River Canyon from a few miles below the confluence of Jefferson Creek to Lake Billy Chinook.

Glacial and Glaciofluvial Deposits

In the western part of the reservation, at altitudes mostly above 4,000 feet, small glacial moraines locally have been reworked by streams. Most and perhaps all of the moraines are deposits from late Pleistocene and Holocene glaciers high in the Cascades and small glaciers still present on Mount Jefferson. Most of the morainal material is unsorted and consists of angular to subangular boulders and cobbles embedded in a sparse sandy matrix composed of rock and mineral fragments from the High Cascades andesites and locally with some admixed pumice; stratification is rare. At lower altitudes, streams have reworked some of the glacial till, producing slightly better sorted and bedded deposits of silt, sand, and gravels.

Late Andesite and Basalt

In the southwestern part of the reservation there are a few small areas of young flows of olivine andesite and basalt. Some of these are on the flanks of well preserved cinder cones (A. C. Waters, unpub. map) and one extensive flow fills the valley of Jefferson Creek near the boundary of the reservation (Walker, Greene, and Pattee, 1966). The vent areas of some of these flows generally consist of accumulations of eruptive fragmental material including scoriaceous cinders, blocks of more massive andesite or basalt, and irregular layers of partly agglutinated lava; commonly a central intrusive plug or conduit and radial or concentric dikes are exposed through the mantle of eruptive flow and fragmental material.

Young Surficial Deposits

Unconsolidated surficial deposits of several kinds occur sparingly on the reservation and all are considered to be of late Pleistocene or Holocene age (Waters, 1968a, 1968b; Robison and Laenen, 1976).

Alluvium, in the form of sand, gravel, silt, and clay in flood plains and channel fill, occurs underlying or adjacent to rivers and streams throughout the reservation and in several large fanlike deposits above stream level on the margins of Schoolie Flat. Only the larger areas of these deposits are shown on Figure 1 and nowhere on the reservation are they more than 50 feet thick. Several areas of landslide deposits are present in the northern part of the reservation, all in areas underlain by the John Day Formation. The largest landslides are in the canyon of the Deschutes River, one near the confluence of Warm Springs River and another between Kaskela and North Junction. Small landslides are present in the John Day Formation along its contact with overlying flows of the Columbia River Basalt Group southwest of the Laughlin Hills. Other small unmapped landslides are on the steep walls of Deschutes River canyon.

Structure

Little detailed information is available concerning the structure of Tertiary and Quaternary rocks exposed on the reservation, although a few faults and folds have been mapped. Deformation that has been recognized in nearby areas mostly predates the volcanic rocks of the High Cascades and, hence, is nearly all Miocene and older. In general the Pliocene and younger rocks are largely undeformed, except for minor local faulting, and most slope gently eastward from the crest of the Cascade Range to the Deschutes River. This eastward inclination results largely from deposition on original slopes marginal to volcanic vent areas localized along the axis of the High Cascades. In a few places flows and associated volcaniclastic rocks are inclined away from isolated vents or domal masses.

Newcomb (1970) shows an east-west anticlinal warp in the Clarno and John Day age rocks in the northeastern part of the reservation and a northeast-trending synclinal warp that apparently projects a short distance into the reservation a few miles north of Pelton Dam on the Deschutes River. A few faults, probably all with normal displacements, have been mapped by Waters (1968b; unpub. geol. map). The most conspicuous of these faults is at the west base of Bald Peter, (Figure 3) where a precipitous scarp suggests a displacement of more than l,000 feet, although part of the relief on the scarp may result from glacial erosion. Another fault with normal displacement follows the drainage of Metolius River from Jefferson Creek north-north- eastward for about 10 miles; its southward projection is at the west base of Green Ridge where normal displacements of at least 1,800 feet are known. Other faults mapped by Waters (unpub. map) include one northwest--trending in the canyon of the Metolius River between Lake Billy Chinook and Whitewater River and one on the southwest side of Sidwalter Buttes.

MINERAL RESOURCES

General

The Warm Springs Indian Reservation is in an area of low mineral potential, and evaluation of the geology indicates that commercial deposits of metallic and nonmetallic minerals are not likely to be found. However, some of the geology in the northeastern part of the reservation is similar to that in nearby areas that contain small to moderate sized commercial mineral deposits.

Metallic Mineral Resources

A few tens of miles southwest of the reservation in the Bohemia, Blue River, Quartzville, and North Santiam mining districts, some ores of gold, silver, copper, lead, and zinc have been produced from fissure veins in Tertiary volcanic rocks, probably the age equivalent of the John Day Formation. The veins probably are late Miocene in age, and are believed to be genetically related to dioritic intrusive rocks (Callaghan and Buddington, 1938). The intrusives may indicate the sites of a former north-trending chain of volcanoes (Peck and others, 1964) now mostly removed by erosion.

No record was found of metallic mineral occurrences on the reservation. The nearest metallic mineral production has been from the Ashwood and Horse Heaven areas, 40 to 50 miles east.

The Oregon King mine, located a little more than 20 miles east of the reservation, produced silver ore valued at over $230,000 between 1898 and 1963. Production was from mesothermal deposits, both cavity-filling and replacement types, related to a tectonic breccia zone and a zone of east-west faulting (Ojala, 1964, p. 1) in rocks of the Clarno and possibly John Day Formations (Libby and Corcoran, 1962).

Mercury has been produced from fissure veins in basalt or basaltic andesite of Miocene age (probably part of Columbia River Basalt Group) in the Oak Grove Fork area (Brooks, 1963, p. 105-111), about 15 miles west of Mount Wilson; several mercury mines are present east of the reservation in rocks of both the Clarno and John Day Formations.

The Horse Heaven area, located in the Ochoco Mountains about 45 miles east of the reservation, has been the site of much of Oregon's mercury production. Between 1934 and 1958, the Horse Heaven mine produced 16,600 flasks of mercury. The Horse Heaven ore bodies are associated with a biotite rhyolite plug which intruded volcanic rocks and sediments. They were formed locally in breccia zones, along faults, and in rhyolite tuffs overlying the intrusive plug (Gilbert, 1958, p. 25).

Energy Resources

General

The only potential energy resources on the reservation are geothermal and hydroelectric. Noncommercial occurrences of uranium are known from the John Day and Clarno Formations both in the Mutton Mountains and in areas south of Prineville. Accumulations of hydrocarbons (coal, oil, and gas) do not occur on or near the reservation.

Geothermal Resources

The presence of both hot springs and young andesitic and basaltic volcanoes on the reservation may indicate some potential for the development of geothermal energy beyond that currently being used at the resort at Kah-Nee-Ta Hot Springs. Data provided by Robison and Laenen (1976), Mariner and others (1974), and by Norman MacLeod and Edward Sammel of the U.S. Geological Survey (letter to Olney Pratt, Chairman, Warm Springs Council, Nov. 14, 1973) indicate that there is a group of warm springs along a 1 ½-mile reach of Warm Springs River, some emerging at river level and others at somewhat higher levels and as much as 100 feet from the river bank. The slightly alkaline spring waters flow directly from fractures in rhyolite or welded tuff of the John Day Formation near its contact with the volcanic rocks of the underlying Clarno Formation. An apparent N. 75º W. alignment of the springs along Warm Springs River suggests to Norman MacLeod and Edward Sammel (written commun., 1973) that the thermal waters may be rising along a single fault near this contact.

Temperatures of the hot-spring waters vary, but are as high as 182ºF (83.5ºC). Furthermore, an even higher aquifer temperature based on water chemistry was computed by Mariner and others (1974) for thermal waters at Kah-Nee-Ta Hot Springs. The silica content (conductive model) suggests 282ºF (139ºC) and the ratio of contained sodium and potassium indicates 217ºF (103ºC); the chemistry indicates that these are mixed waters so that rock temperatures at depth may be somewhat higher.

The potential for geothermal energy related to the large and young volcanoes of the High Cascade Range, such as Mount Jefferson, is difficult to evaluate. Most and perhaps all of the volcanic activity at Mount Jefferson is Pleistocene in age, and the limited amount of glaciation on the mountain suggests that it is largely late Pleistocene. Whether this volcanism is sufficiently young for molten magma or large volumes of hot rock to persist at relatively shallow depth beneath the volcano remains to be demonstrated. There are no large volumes of young rhyolitic or dacitic volcanic rocks on Mount Jefferson or on other smaller young volcanoes in the western part of the reservation. This paucity of young silicic volcanic rocks in this part of the Cascade Range suggests a rather low potential for the development of geothermal energy.

Kah-Nee-Ta hot springs, located in Secs. 19 and 20, T. 8 S., R. 13 E., about 9 miles northeast of Warm Springs, has been developed into a resort complex including mineral baths, hotel, restaurant, and camping facilities. The springs are not now being used for space heating. Water from the hot springs has been analyzed by the U.S. Geological Survey (Mariner and others, 1974); results are listed in Table 1.

Kah-Nee-Ta hot springs' chemical composition is characteristic of that of hot water-dominated systems, as compared to vapor-dominated (dry steam) systems developed for electric power generating (Mariner and others, 1974, p. 21). Most hot water systems are characterized by hot springs that discharge at the surface. The chemical composition, areal-distribution and associated hydrothermal alteration near the springs are useful in providing evidence on probable subsurface temperatures, volumes, and heat contents (White and Williams, 1975, p. 7).

White and Williams (1975, p. 7) divide hot-water convection systems into three temperature ranges: (1) above 150º C - systems may be considered for generation of electricity; (2) from 90º C to 150º C - attractive for space and process heating; and (3) below 90º C - systems are likely to be used for heat only on a local basis and under very favorable circumstances.

On the basis of temperature alone the Kah-Nee-Ta hot springs appears to have potential for space heating and hydroponics. Detailed geological and geophysical surveys are needed to fully assess the potential.

TABLE 1

Physical and Chemical Character of Kah-Nee-Ta Hot Springs

(Mariner, Rapp, Willey, and Presser, 1974, p. 10-20.) (White and Williams, 1975, p. 46-47)

Spring water	
Temperature (°C)	52°
pH	8.32
Specific conductance	1370
Silica (SiO_2)	104 mg/l
Calcium (Ca)	3.2 mg/l
Magnesium (Mg)	.05 mg/l
Sodium (Na)	325 mg/l
Potassium (K)	3.4 mg/l
Lithium (Li)	.52 mg/l
Bicarbonate (HCO_3)	493 mg/l
Carbonate (CO_3)	9 mg/l
Sulfate ($S0_4$)	34 mg/l
Chloride (Cl)	155 mg/l
Fluoride (F)	21 mg/l
Boron (B)	2.6 mg/l
Flow of spring	200 liters per minute
Gas	trace
Spring deposits	
$CaCO_3$	trace
Silica	--
Rock type at spring: rhyolite, andesite, basalt, tuff	
Estimated thermal aquifer temperature	
Silica conductive	139°C
Silica adiabatic	135°C
Na-K	17°C
Na-K-⅓ca	103°C
Na-K-¼ca	121°
Reservoir assumptions	
Subsurface area	1.5 km^2
Thickness	1.5 km
Volume	2.25 km^3

Hydroelectric Power

Round Butte and Pelton Dams, two sources of hydroelectric power, are adjacent to the reservation. They are owned and operated by Portland General Electric Co. Because half of each dam site is on reservation land, the Confederated Tribes receive an annual rent from the electric company.

Round Butte Dam has a total installed generator capacity of 247,050 kilowatts, and that of Pelton Dam is 108,000 kilowatts (Pacific Northwest River Basins Commission, 1972, p. L-7 and

L-5). Lake Billy Chinook, the reservoir behind Round Butte Dam, has a storage capacity of 535,000 acre feet with a surface area of approximately 4,000 acres. Lake Simtustus, behind Pelton Dam, has a storage capacity of 32,000 acre-feet with a surface area of 360 acres (Oregon State Water Resources Board, 1969, P. 99).

In addition to the above existing damsites, two areas close to the Deschutes River near the northeastern edge of the reservation are being evaluated by the Corps of Engineers as potential pumped storage sites as a source of supplemental peaking capacity (U.S. Army Corps of Engineers, 1976, p. 102-103 and Figure 25).

Uranium

Occurrences of uranium minerals are known from some Miocene age rocks in the Mutton Mountain and in areas south of Prineville (White, 1949). Apparently none are currently of economic importance.

Nonmetallic Mineral Resources

General

Nonmetallic commodities occurring on or adjacent to the reservation are perlite, volcanic tuff, diatomite, zeolites, gem stones (thunder eggs and black agate), and sand and gravel. Rock suitable for both riprap and crush stone are abundant.

The only active mining operation is a small building stone quarry (Nasweytewa, personal commun., 1976). The amount of pumice, cinders, or scoria produced from deposits on the reservation is not known. Quarry and borrow pits are plotted on Figure 1.

Perlite

General.--Perlite is a glassy volcanic rock which occurs in flows consisting of thick accumulations of pyroclastic debris and other rocks. Its composition ranges from rhyolite to that of andesite and it contains 2 to 5 percent water (Chesterman, 1975, p. 927). When perlite is heated rapidly under controlled conditions, it expands into a porous, frothy material having low bulk density, low thermal conductivity, high resistance to fire, and low sound transmission. These properties make perlite useful for aggregate and insulating material.

In 1974, the average price of crushed, cleaned, and sized crude perlite sold to expanding plants was $11.89 per short ton f.o.b. mine (U.S. Bureau of Mines, 1976). Expanded perlite had an average value of $73.29 per ton (Meisinger, 1975, p. 9).

Occurrence.--Between 1946 and 1954, perlite was mined and milled at the Lady Frances mine just north of the reservation in the NE¼ sec. 24, T. 6 S., R. 13 E. (Figure 2). Development of the property was begun by Dant and Russell, Inc. of Portland in 1945. They completed a pilot plant in 1946 and began production in 1947. Initial mining was underground and over 2,000 feet of workings were driven. After 1948, mining was by open pit (Eng. and Mining Jour., 1948, p. 67). The mine operated more or less continuously until 1952 when the operation was leased to Kaiser Gypsum

Co. In May 1953, Kaiser relinquished the lease and Dant and Russell resumed operations. Two thousand tons of crude perlite were mined and 4,100 tons of expanded perlite valued at $81,000 were sold or used to manufacture acoustical tile (U.S. Bureau of Mines, 1956, p. 839). Mining stopped and the plant was dismantled in 1954. There is no record of any activity since that time (U.S. Bureau of Mines, 1955-1972).

The Clarno Formation contains perlite in central Oregon. Figure 3 shows the extent of this formation within the reservation (Waters, 1968, maps). At the Lady Frances mine, the main perlite zone is in a platy, aphanitic, gray trachyte overlain by a thin bed of black glass (Allen, 1946, p. 2). Near the mine the perlite crops out at three localities: at and near the mine portal, 2,000 feet south along Eagle Creek and over the ridge to the northwest. Allen believes these occurrences are connected beneath the soil cover. The principal perlite zone is 150 feet thick at the mine portal, but 400 feet south it is less than 30 feet thick. A rhyolite plug (400 feet by 800 feet) north of the mine portal is surrounded on three sides by perlite and may represent the vent for the eruption (Allen, 1946, p. 4).

A perlite deposit, known as the Axford-Hunt, occurs across the Deschutes River about 3 miles east of the Lady Frances mine (Mason, 1951, p. 14). Other information concerning the deposit is unknown.

A reported perlite occurrence is on the reservation near Simnasho in T. 7 S., R. 12 E. (Oregon State Water Resources Board, 1961, p. 6). No other information was found concerning this occurrence.

Uses.--The construction industry consumes about 60 percent of domestic perlite production, primarily as aggregate in insulation boards (Chesterman, 1975, p. 927). The end uses of expanded perlite in 1973 were: filter aid 19 percent, plaster aggregate 10 percent, concrete aggregate 7 percent, horticultural aggregate 5 percent, low-temperature insulation 2 percent, masonry and cavity fill insulation 1 percent, fillers 2 percent, formed products 8 percent; the other 46 percent includes insulation board and lesser uses such as paint textures, bonding agents, polishing compounds and miscellaneous industrial and agricultural products (U.S. Bureau of Mines, 1973, p. 900).

Perlite aggregate plaster dries quickly, lends itself to machine applications, and has relatively high elasticity. Portland cement concrete made with perlite aggregate offers up to 20 times more thermal insulation than does conventional concrete. The high silica content of perlite and its high adsorptive properties render it chemically inert in many environments and suitable for filters and fillers (Chesterman, 1975, p. 927-928).

Specifications.--Because low-bulk density is essential, the total volume of non-expansible materials should not exceed 20 percent of the furnace feed. Perlite ores may have a wide variety of characteristics, such as degree of vesiculation and range of colors. However, the expanded perlite products should have a light or white color for most applications.

The ASTM (American Society for Testing Materials) standards for perlite used in plaster specify that aggregate shall not weigh less than

7-½ nor more than 15 pounds per cubic foot. That used in insulating concrete shall not be less than 7-½ nor more than 12 pounds per cubic foot; for horticulture the density should not be less than 5.0 pounds nor more than 8.0 pounds per cubic foot (Chesterman, 1975, p. 928).

Chemical analysis of perlite samples from the Lady Frances mine compared with analyses of the perlite from other areas are included in Table 2.

Mining Methods.--Most developed perlite deposits are large enough and the location and geology such that they can generally be mined by open pit methods. Sites with a minimum of overburden are usually selected. The perlite can be mined by ripper-equipped bulldozers, or, if the material is dense, the rock can be loosened by blasting. Trucks and carryalls are normally used for transportation to shipping points or storage facilities (Chesterman, 1975, p. 931).

Milling and Processing Methods.--The general milling procedure for perlite is described by Chesterman (1975, p. 931-932). The quarried perlite is reduced by crusher to minus five-eighths inch size. If necessary, the crushed ore is treated in a rotary dryer to reduce the free moisture content to less than 1 percent. The dried perlite is further crushed to produce appropriate furnace feed for specified products. The sized perlite is then stored in bins from which it is withdrawn for blending and mixing. The minus 100-mesh fraction, detrimental to the final product, is removed by air classification. These fines constitute as much as 25 percent of the mill feed and are rejected.

Two basic types of furnaces are used to process perlite: (1) the rotary horizontal, and (2) one of several varieties of stationary vertical furnaces.

Properly sized perlite is injected into a furnace and heated. Expansion (popping) takes place between 1400-1800ºF when perlite becomes plastic and the entrapped water escapes as steam, expanding the hot perlite particles. As the particles expand they are withdrawn from the furnace by a suction fan and passed through a system of cyclone classifiers to remove excessive fines and to collect the expanded material. The product is bagged for shipment.

Volcanic Tuff

General.--Volcanic tuff is essentially a lightweight volcanic rock composed primarily of cemented particles of ash and pumice with minor amounts of obsidian, basalt, and other volcanic rock fragments.

Occurrence.--Occurrences of volcanic tuff suitable for building stone are near the Mutton Mountains. One occurrence, the Pine Grove deposit (Rainbow quarry) is in the NW¼, Sec. 11, T. 6 S., R. 11 E. (Figure 1). According to Mason (1951, p. 18) the tuff is platy and greenish to gray to buff with dark red or brown bands. According to the Bureau of Mines (Mineral Yearbook, 1956, p. 934), the stone was used primarily as a decorative stone and marketed as "Rainbow Rock," so named because of the various shades of red, pink, and brown.

The only rock quarry in operation on the reservation is in the S½ NW¼ sec. 1, T. 7 S., R. 12 E. Only a small amount of production is anticipated (Nasewytewa, personal commun., 1976).

Other quarry sites shown on Figure 1 are presumed to have supplied materials for local road building and maintenance needs.

Characteristics and Uses.--The volcanic tuff in Oregon has characteristics that make it desirable for dimension stone (Mason, 1951, p. 15): it is easily quarried and shaped, is relatively light weight, and resists decomposition by weathering. Many deposits, such as at the Rainbow quarry, have a pleasing color and texture. Tuff has the advantage of hardening with exposure to weathering. Because tuff can be cut and shaped with simple equipment, costs are low.

Dimension stone is in competition with cheaper, artificial and more uniform materials (Power, 1975, p. 157). Because most natural stone contains variations in color, it is difficult for quarries to produce a uniform product. An attempt to do so increases production cost and waste at the quarries.

Mining Methods.--Most dimension stone quarries cover a relatively small surface area, and are worked from top to bottom and seldom exceed a depth of 200 feet. Quarrying involves isolating a mass of stone, cutting it free on all sides except one. The isolated block is then lifted and broken free from the parent mass. If the freed block is too large to be sold, it is subdivided into smaller blocks, removed from the quarry, and sent to the mill. Typical mill blocks usually range in size from 15 to 30 tons, but may be as large as 70 tons (Power, 1975, p. 167).

Marketing Potential.--The marketing potential of dimension stone is governed by such things as color, pattern, and texture. Soundness or freedom from flaws is one of the most important factors, and yet one of the most difficult to determine. Special handling methods are required to extract and transport the stone. The total output of a quarry is small compared to other industrial rocks and minerals. Such factors as size of the deposit, amount of overburden, distance to the market, availability of transportation, labor, power, and other utilities must be carefully considered. Few deposits would justify building special roads, rail lines, or utilities for the quarry operation alone (Power, 1975, p. 173).

The principal uses for domestically produced rough dimension stone are in monumental, architectural, and construction applications.

Pumice and Volcanic Cinder

Pumice is a light-colored, cellular, almost frothy rock made up of glass-walled bubble casts. It may occur as coherent, massive blocks composed of highly vesicular glassy lava in either a flow or vent-filling, or it may be more or less fragmented (Peterson and Mason, 1975, p. 991). Volcanic cinders are reddish to black vesicular fragments formed during explosive eruptions of volcanoes. Cinder cones several hundred feet high may be produced during such an eruption.

The main uses of pumice and cinders are in the construction industry as road surfacing material, railroad ballast, building block aggregate, lightweight structural concrete, and plastic aggregate.

There are no reported deposits of pumice and volcanic cinders on the reservation. However, because the reservation area borders the High Cascades it is possible that pumice and volcanic cinder deposits are present.

Diatomite

General.--Diatomite is a siliceous sedimentary rock composed principally of the fossilized skeletal remains of diatoms, single-celled aquatic plants related to algae. Diatomite has been formed by the induration of diatomaceous ooze and consists mainly of diatomaceous silica, a form of opal formed in the cell walls of the living organism (Kadey, 1975, p. 605).

Occurrence.--Baldwin (1946, p. 5) reports a diatomite deposit about 45 feet thick in the NW¼ sec. 25, T. 11 S., R. 11 E. The diatomite bed lies between two basalt flows exposed in a river gorge. The overlying basalt ranges from 3 to 15 feet thick. This diatomite occurrence may now be below the waters of Lake Billy Chinook.

Between 1920 and 1961, diatomite was mined extensively near Terrebonne, Deschutes County, about 30 miles south of Madras. This deposit underlies 800 acres and had a usable thickness of 22 to 28 feet. Original exposures were apparently small and unimpressive. Terrebonne diatomite is of high quality. Much of the diatomite was used as a filler medium in the manufacture of sugar and antibiotics (Wagner, 1969, p. 208-210).

Uses.--Processed diatomite has a structure and chemical stability that renders it suitable for certain applications. The primary use is as a filler aid, which accounts for more than 60 percent of the domestic demand (U.S. Bureau of Mines, 1973, p. 499). The diatom structure, low bulk density, high absorptive capacity, high surface area, and relatively low abrasion make diatomite valuable as a filler and an extender in paint, paper, rubber, and plastics, as an anti-caking agent, as thermal insulating material, as a catalyst carrier, as a chromatographic support, and as a polish, abrasive, and pesticide extender (Kadey, 1975, p. 605).

Specifications.--In evaluating a diatomite deposit, the following criteria must be considered (Kadey, 1975, p. 618): (1) color--the whiter the color the more desirable it is as a filler, (2) low bulk density--indicates freedom from contaminants such as sand and clay, (3) low degree of consolidation--highly consolidated diatomite is hard to mill and generally has a degraded structure. Chemical analysis becomes important only after the physical suitability has been ascertained.

Gem Stones

According to Dake (1945, p. 86), the Mutton Mountains area of the Warm Springs Indian Reservation is noted for its "thunder eggs," geodes, and so-called "black" agate. The southern portion of the reservation is noted for the large masses of fine "black" agate in addition to the usual "thunder eggs."

Some of the opal, chalcedony, and agate from the Mutton Mountains area is coated by minute particles of secondary uranium minerals, and often exhibit a pale-green to yellow fluorescence. None of the uranium minerals are considered to be present ln commercial quantities (White, 1949, p. 2-3).

At the present time the Tribe does not allow rock collecting or prospecting on the reservation by non-Indians. There has been no attempt to develop any tribal-sponsored digging areas.

Aggregate

Material suitable for concrete aggregate is abundant throughout the reservation. Well sorted gravels, locally more than 100 feet thick and composed largely of andesite boulders, are found on Miller Creek Flat. Other local sources of sand and gravel may be found near present drainages and in several large fan-like deposits on the margins of Schoolie Flat. Rock suitable for riprap and crushed stone is abundant throughout the area.

Potential Mineral Resources

Although no significant mineral deposits are known on the reservation, there may be some potential for lithium and zeolites.

Recent geochemical surveys have shown that lithium is present in significant amounts in sequences of silicic volcaniclastic rocks of middle and late Cenozoic age similar to those of parts of the John Day and Dalles Formations.

Zeolites, which have unique physical and chemical properties for purification of liquids and gases, have been identified in most sections of the John Day Formation and, at least locally, in sections exposed in the northeast part of the reservation. Whether any of these deposits will ultimately be developed for the extraction of zeolites remains to be determined.

ENVIRONMENTAL EFFECTS

Mining of perlite, dimension stone, cinders, and diatomite would be by surface operations. Because of the low potential for large-scale development of these commodities, the resulting disturbance would be very limited, and with proper planning the disturbed areas could be reclaimed.

Development of the mineral resources probably would not require major road construction as the existing network of dirt and gravel roads covers most of the reservation. Short connecting roads from the mine or quarry sites and widening of some present roads would most likely be adequate.

Development of geothermal resources for greenhouse heating or space heating would result in very little surface disruption. If the hot springs are found to be suitable for geothermal energy production, the construction of power plants, cooling towers, and steam gathering lines will be necessary. This will have an impact on the land primarily during the developmental stage and over a limited area. As construction of the geothermal field is completed, much of the area could be used for other purposes (Bowen, 1973, p. 213).

RECOMMENDATIONS FOR FURTHER WORK

1. Areas underlain by the Clarno and John Day Formations, with special reference to areas of rhyolite flow, domes, and plugs, should be examined geologically and geochemically for mercury, uranium, lithium, and zeolites.
2. Further study of the Kah-Nee-Ta hot springs and the surrounding area appears warranted.
3. The perlite occurrences in the Mutton Mountains area should be mapped and sampled.
4. An investigation of the gem stone potential on Indian land should be made to determine source areas and market possibilities.

REFERENCES

Allen, J. E., 1946, Perlite deposits near the Deschutes River, southern Wasco County, Oregon: Oregon Dept. of Geology and Mineral Industries Short Paper 16, 17 p.

_____,1947, Another perlite deposit in Oregon: Oregon Dept. of Geology and Mineral Industries, The Ore Bin, v. 9, no. 8, p. 60-62.

Armstrong, R. L., Taylor, E. M., Hales, P. O., and Parker, D. J., 1975, K-Ar dates for volcanic rocks, central Cascade Range, Oregon: Isochron/West, no. 13, p. 5-10.

Anderson, F. G., Selvig, W. A., Baur, G. S., Colbassani, P. J., and Bank, Walter, 1956, Composition of perlite: U.S. Bur. Mines Rpt. Inv. 5199, 13 p.

Baldwin, E. M., 1946, Diatomite: Oregon, Dept. of Geology and Mineral Industries, The Ore Bin, v. 8, no. 1, p. 1-10.

Bowen, R. G., 1973, Environmental impact of geothermal development in Kruger, Paul and Otte, Carel, eds., Geothermal Energy: Resources, Production, Stimulation: Stanford University Press, Stanford, Ca., p. 197-215.

Brooks, H. C., 1963, Quicksilver in Oregon: Oregon Dept. Geology and Mineral Industries Bull. 55, 223 p.

Callahan, Eugene, and Buddington, A. F., 1938, Metalliferous mineral deposits of the Cascade Range in Oregon: U.S. Geol. Survey Bull. 893, 141 p.

Chesterman, C. W., 1975, Perlite, in Lefond, Stanley J., ed., Industrial Minerals and Rocks, 4th ed., AIME, p. 927-934.

Dake, H. C., 1945, Notes on quartz minerals of Oregon: The Mineralogist, v. XIII, no. 3, p. 83-86.

Engineering and Mining Journal, 1948, The Lady Frances mine - a new source of perlite: v. 149, no. 1, p. 66-67.

Gilbert, J. E., 1958, Horse Heaven mine, Jefferson County, Oregon: State of Oregon, Dept. of Geol. and Mineral Industries, The Ore Bin, v. 20, no. 3, p. 25-29.

Godwin, L. H., Haigler, L. B., Rioux, R. L., White, D. E., Muffler, L. J. P., and Wayland, R. G., 1971, Glassification of public lands valuable for geothermal steam and associated geothermal resources: U.S. Geol. Survey Circ. 647, 18 p.

Groh, E. A., 1966, Geothermal energy potential in Oregon: Oregon Dept. of Geology and Mineral Industries, The Ore Bin, v. 28, no. 7, p. 125-135.

Hodge, E. T., 1932, Geologic map of north-central Oregon: Oregon Univ. (Eugene) Pub., geology ser., v. 1, no. 5, scale 1:250,000; accompanying text, 7 p.

_____,1941, Geology of the Madras quadrangle: Oregon State Coll. (Corvallis), Studies in geology no. 1, scale 1:125,000.

_____,1942, Geology of north-central Oregon: Oregon State Coll. (Corvallis), Mon., Studies in geology no. 3, 76 p.

Hull, D. A., and Newton, V. C., Jr., 1976, Geothermal activity in 1975: Oregon Dept. of Geology and Mineral Industries, The Ore Bin, v. 38, no. 1, p. 10-17.

Kadey, F. L., Jr., 1975, Diatomite, in Lefond, S. J., ed., Industrial Minerals and Rocks, 4th ed., AIME, p. 605-635.

Libbey, F. W., and Corcoran, R. E., 1962, The Oregon King mine, Jefferson County, Oregon: Oregon Dept. Geology and Mineral Industries Short Paper 23, 49 p.

Mariner, R. H., Rapp, J. B., Willey, L. M., and Presser, T. S., 1974, The chemical composition and estimated minimum thermal reservoir temperatures of selected hot springs in Oregon: U.S. Geol. Survey open-file rept., 27 p.

Mason, R. S., 1951, Light-weight aggregate industry in Oregon: Oregon Dept. Geology and Mineral Industries Short Paper 21, 23 p.

Merriam, J. C., l901a, A geological section through the John Day Basin, in editorial: Jour. Geology, v. 9, no. 1, p. 71-72.

_____,l901b, A contribution to the geology of the John Day Basin [Oregon]: California Univ. Geology Bull., v. 2, no. 9, p. 269-314.

Meisinger, A. C., 1975, Perlite Chapter (preprint) in Minerals, Facts, and problems, U.S. Bureau of Mines, p. 1-12.

Newcomb, R. C., 1966, Lithology in eastward extension of the Dalles Formation, Oregon and Washington, in Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550-D, D59-D63.

_____,1970, Tectonic structure of the main part of the basalt of the Columbia River Group, Washington, Oregon, and Idaho: U.S. Geol. Survey Misc. Geol. Inv. Map I-587, scale 1:500,000.

Ojala, G. L., 1964, Geology of the Oregon King mine and vicinity, Jefferson County, Oregon: Kansas Univ., unpub. M.S. thesis, 123 p.

Oregon State Water Resources Board, 1961, Deschutes River Basin, 188 p.

_____,1969, Oregon's long-range requirements for water, 397 p.

Peck, D. L., 1964, Geologic reconnaissance of the Antelope-Ashwood area, north-central Oregon with emphasis on the John Day Formation of late Oligocene and early Miocene age: U.S. Geol. Survey Bull. 1161-D, p. Dl-D26.

Peck, D. L., Griggs, A. B., Schlicker, H. G., Wells, F. G., and Dole, H. M., 1964, Geology of the central and northern parts of the Western Cascade Range in Oregon: U.S. Geol. Survey Prof. Paper 449, 56 p.

Peterson, N. V., and Groh, E. A., 1970, Geologic tour of Cove Palisades State Park near Madras, Oregon: Ore Bin, v. 32, no. 8, p. 141-168.

Peterson, N. V., and Mason, R. S., 1975, Pumice, pumicite, and volcanic cinders, in Lefond, S. J., ed., Industrial Minerals and Rocks, 4th ed., AIME, p. 991-994.

Power Planning Committee, Pacific Northwest River Basins Commission, 1972, Plant data sheets of hydroelectric and steam-electric plants of the Pacific Northwest, 25 p. + data sheets.

Power, W. R., 1975, Construction materials - dimension and cut stone, in Lefond, S. J., ed., Industrial Minerals and Rocks, 4th ed., AIME, p. 157-174.

Robinson, P. T., 1975, Reconnaissance geologic map of the John Day Formation in southwestern part of the Blue Mountains and adjacent areas, north-central Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-872, scale 1:125,000.

Robison, J. H., and Laenen, Antonious, 1976, Water resources of the Warm Springs Indian Reservation, Oregon: U.S. Geol. Survey Water Resources Inv., 76-26, 85 p.

Stearns, H. T., 1931, Geology and water resources of the middle Deschutes River Basin: U.S. Geol. Survey Water-Supply Paper 637-D, p. 125-220.

Swanson, D. A., 1969, Reconnaissance geologic map of the east half of the Bend (AMS) quadrangle, Crook, Wheeler, Jefferson, Wasco, and Deschutes Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-568, scale 1:250,000.

Swanson, D. A., and Robinson, P. T., 1968, Base of the John Day Formation in and near the Horse Heaven mining district, north-central Oregon, in Geological Survey research 1968: U.S. Geol. Survey Prof. Paper 600-D, p. D154-D161.

Thayer, T. P., 1936, Structure of the North Santiam River section of the Cascade Mountains in Oregon: Jour. Geology, v. 44, no. 6, p. 701-716.

_____,1937, Petrography of later Tertiary and Quaternary rocks of the north-central Cascade Mountains in Oregon, with notes on similar rocks in western Nevada: Geol. Soc. America Bull., v. 48, no. 11, p. 1611-1651.

U.S. Army Corps of Engineers, 1976, Pumped--storage inventory of the Pacific Northwest: North Pacific Division, Corps of Engineers, Rept. No. 26, 104 p.

U.S. Bureau of Mines, 1956, The mineral industry of Oregon, in Minerals Yearbook - 1953, v. III, Area reports, 1292 p.

_____,1974, Area reports: domestic, v. II of Minerals Yearbook 1972: Washington, U.S. Govt. Printing Office, 805 p.

_____,Minerals Yearbooks - 1955-1972.

_____,1975, Metals, minerals, and fuels, v. I, of Minerals Yearbook 1973:Washington, U.S. Govt. Printing Office,1383 p.

_____,1976, Commodity Data Summaries, 196 p.

U.S. Department of Commerce, 1974, Federal and State Indian Reservations and Indian Trust Areas: U.S. Govt. Printing Office, Washington, 604 p.

Wagner, N. S., 1969, Diatomite, in Weissenborn, A. E., ed., Mineral and water resources of Oregon: State of Oregon, Dept. of Geol. and Mineral Industries Bull. 64, 462 p.

Walker, G. W., Greene, R. C., and Pattee, E. C., 1966, Mineral resources of the Mount Jefferson Primitive Area, Oregon: U.S. Geol. Survey Bull. 1230-D, p. Dl-D32.

Waring, G. A., 1965, Thermal springs of the United States and other countries of the world - a summary: U.S. Geol. Survey Prof. Paper 492, 383 p.

Waters, A. C., 1954, John Day Formation west of its type locality [Oreg.] [abs.]: Geol. Soc. America Bull., v. 65, no. 12, pt. 2, p. 1320.

_____,1968a, Reconnaissance geologic map of the Dufur quadrangle, Hood River, Sherman, and Wasco Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-555, scale 1:125,000.

______,1968b, Reconnaissance geologic map of the Madras quadrangle, Jefferson and Wasco Counties, Oregon: U.S. Geol. Survey Misc. Geol. Inv. Map I-556, scale 1:125,000.

Waters, A. C., Brown, R. E., Compton, R. R., Staples, L. W., Walker, G. W., and Williams, Howel, 1951, Quicksilver deposits of the Horse Heaven mining district, Oregon: U.S. Geol. Survey Bull. 969-E, p. 105-149.

Wells, F. G., and Peck, D. L., 1961, Geologic map of Oregon west of 121st meridian: U.S. Geol. Survey Misc. Geol. Inv. Map I-325, scale 1:500,000.

White, D. J., 1949, Radioactive ores the prospector should know: Oregon Dept. of Geology and Mineral Industries Short Paper, no. 18, 14 p.

White, D. E., and Williams, D. L., Editors, 1975, Assessment of Geothermal resources of the United States 1975: U.S. Geol. Survey Circ. 726, 155 p.

Wilkinson, W. D., 1932, Petrography of the Mutton Mountains formations of Oregon: Oregon Univ., Eugene, Ph. D. thesis.

Williams, Howel, 1942, The geology of Crater Lake National Park, Oregon, with a reconnaissance of the Cascade Range southward to Mount Shasta: Carnegie Inst. Washington Pub. 540, 162 p.

1944, Volcanoes of the Three Sisters region, Oregon Cascades: California Univ Dept. Geol. Sci. Bull., v. 27, no. 3, p. 37-83.

_____,1957, A geologic map of the Bend quadrangle, Oregon, and a reconnaissance geologic map of the central portion of the High Cascade Mountains: Oregon Dept. Geology and Mineral Industries, in cooperation with U.S. Geol. Survey, scales 1:125,000 and 1:250,000.

Table 2 Click back button (<<) on toolbar to return to text

Analyses of perlite mined at the Lady Frances mine compared to perlited mined at other localities in the U.S.
(NA - Not Available)

Constituent	1	2	3	4	5	6	7	8
SiO_2	73.79	73.28	73.6	73.1	74.4	73.6	74.1	71.4
Al_2O_3	12.40	12.55	13.2	12.8	12.4	12.7	13.3	13.7
Fe_2O_3	.52	.58	NA	NA	NA	NA	NA	NA
FeO	.62	.63	NA	NA	NA	NA	NA	NA
Total Fe	NA	NA	.8	.7	.9	.7	.5	.9
MgO	.11	.08	.1	.2	.1	.2	.1	.2
CaO	.80	.80	.6	.9	.7	.6	.6	.5
Na_2O	3.16	2.97	4.1	3.0	3.5	3.2	3.5	2.9
K_2O	4.84	5.00	4.1	4.7	4.7	5.0	4.6	4.9
H_2O+	3.24	3.60	3.3	3.9	3.3	3.8	3.5	4.9
H_2O-	.25	.19	.1	.6	.1	.3	.1	.2
TiO_2	.09	.09	.07	.08	.13	.10	.05	.10
P_2O_5	.01	.01	NA	NA	NA	NA	NA	NA
MnO	.02	.02	NA	NA	NA	NA	NA	NA

*1. Lady Frances mine
*2. Lady Frances mine
**3. Big Pine, Inyo County, Calif.
**4. Pioche, Lincoln County, Nev.
**5. Milford, Beaver County, Utah
**6. Superior, Pinal County, Ariz.
**7. Socorro, Socorro County, N.M.
**8. Rosita, Custer County, Colo.

* Source: Allen, 1946, p. 14
** Source: Anderson and others, 1956, p. 5.

Click back button (<<) on toolbar to return to text

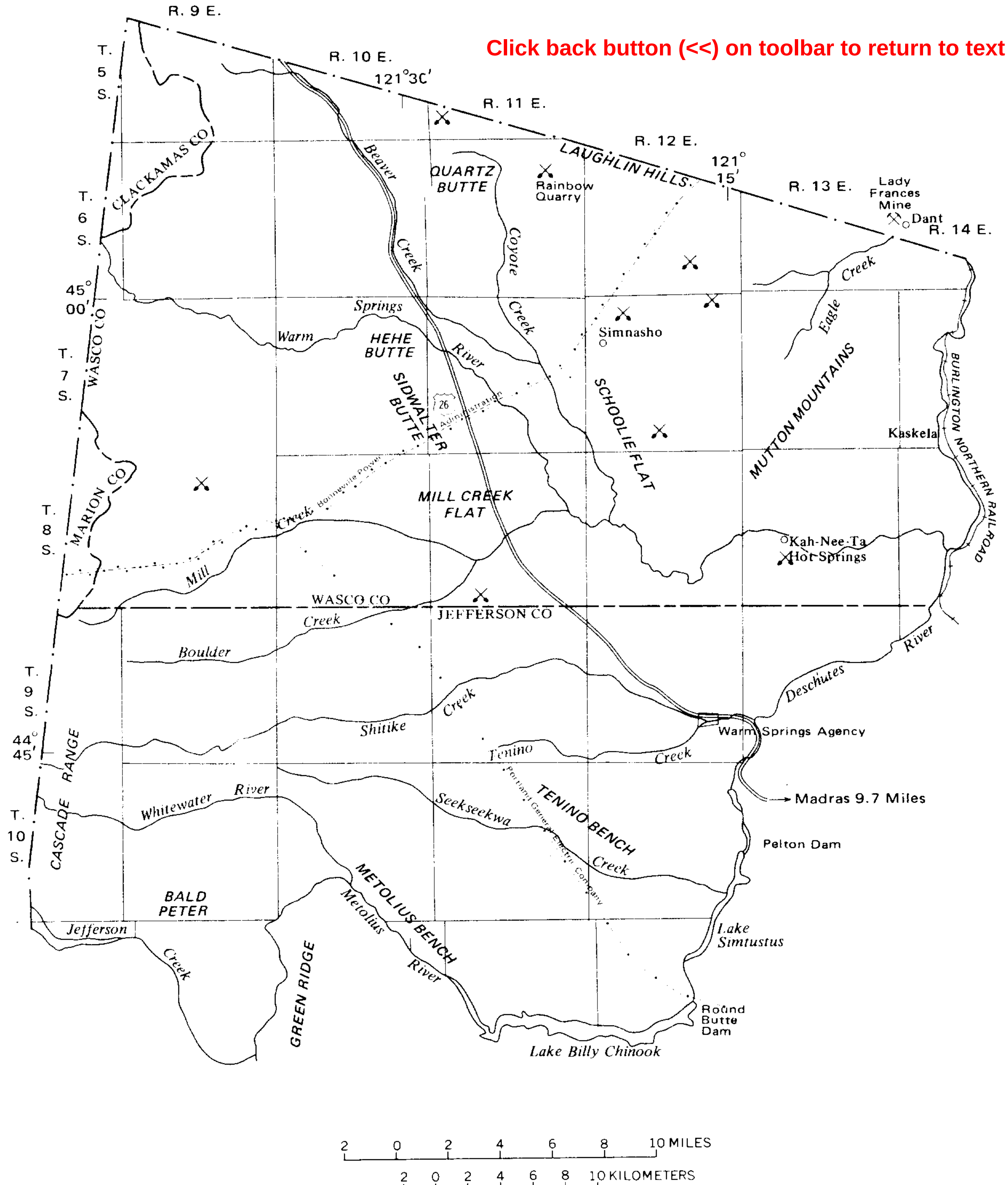


Figure 1. Index map of Warm Springs Indian Reservation.

Click back button (<<) on toolbar to return to text

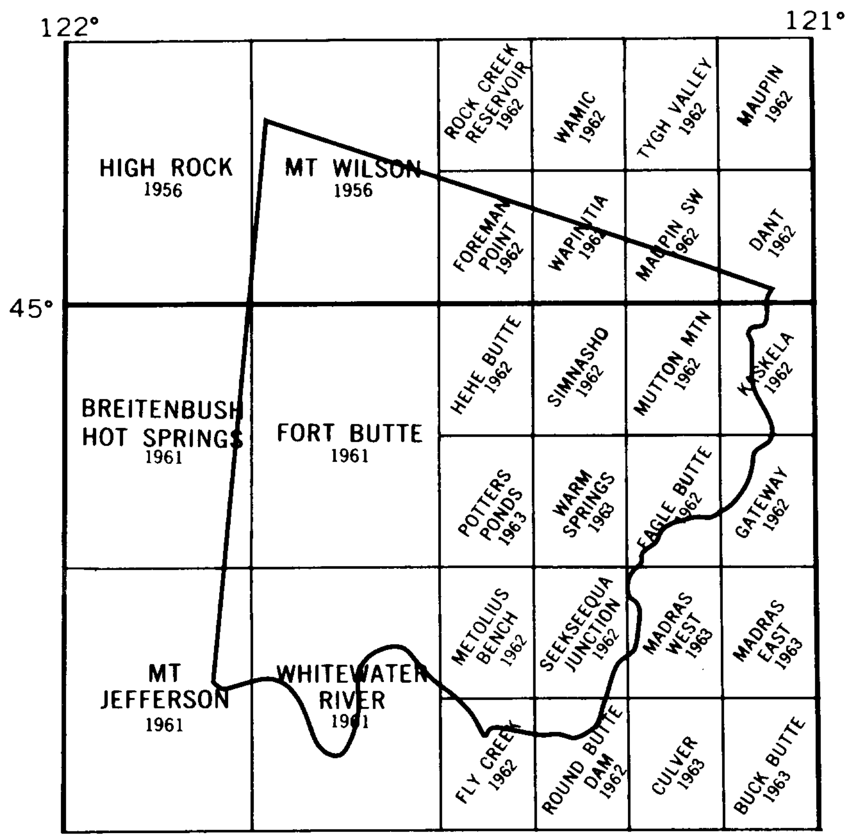
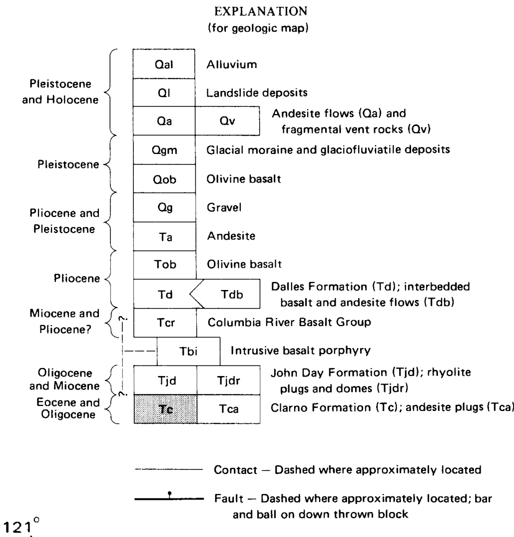


Figure 2. Topographic map index for Warm Springs Indian Reservation.

Click back button (<<) on toolbar to return to text



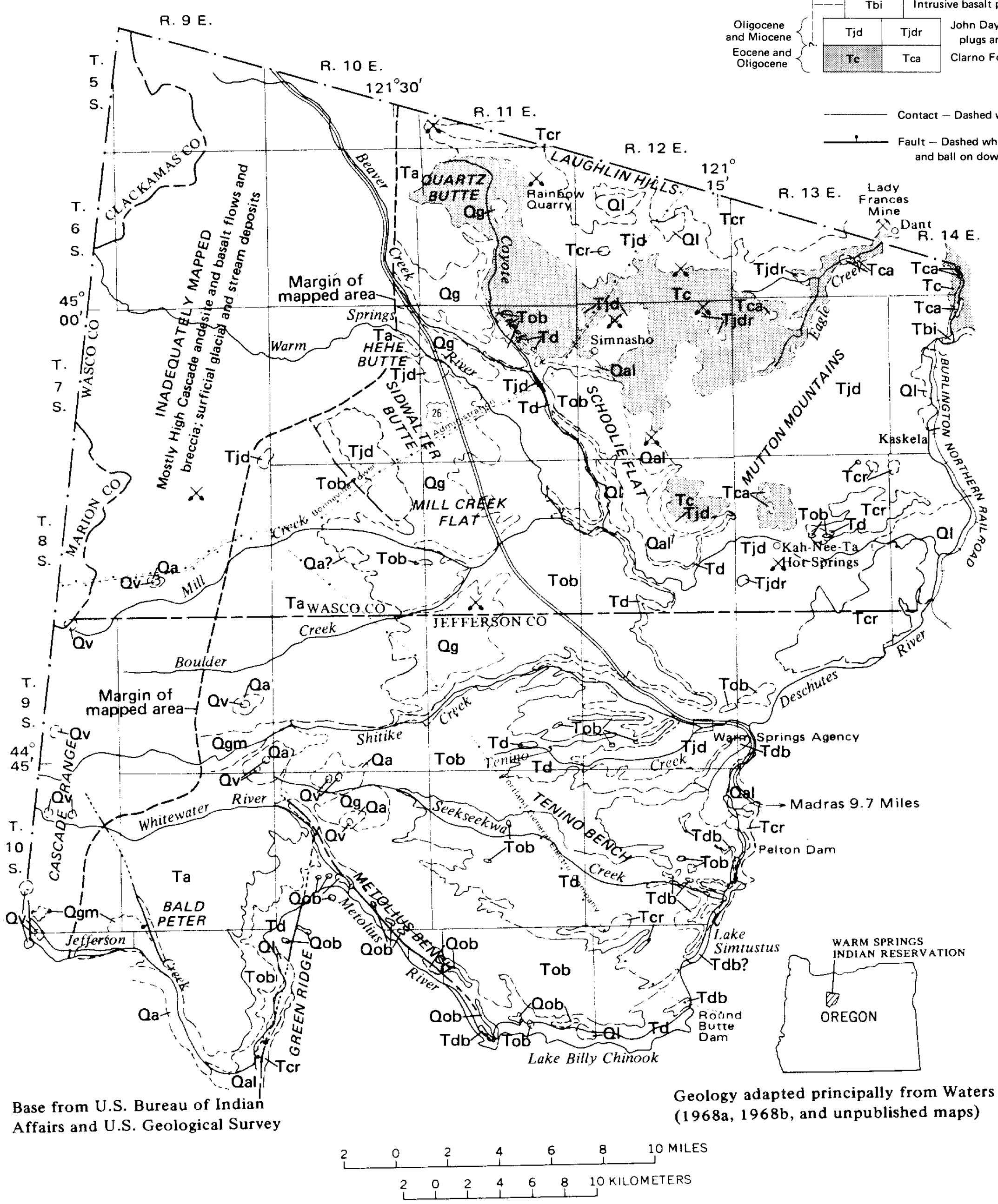


Figure 3. Geologic map of Warm Springs Indian Reservation.

Click back button (<<) on toolbar to return to text

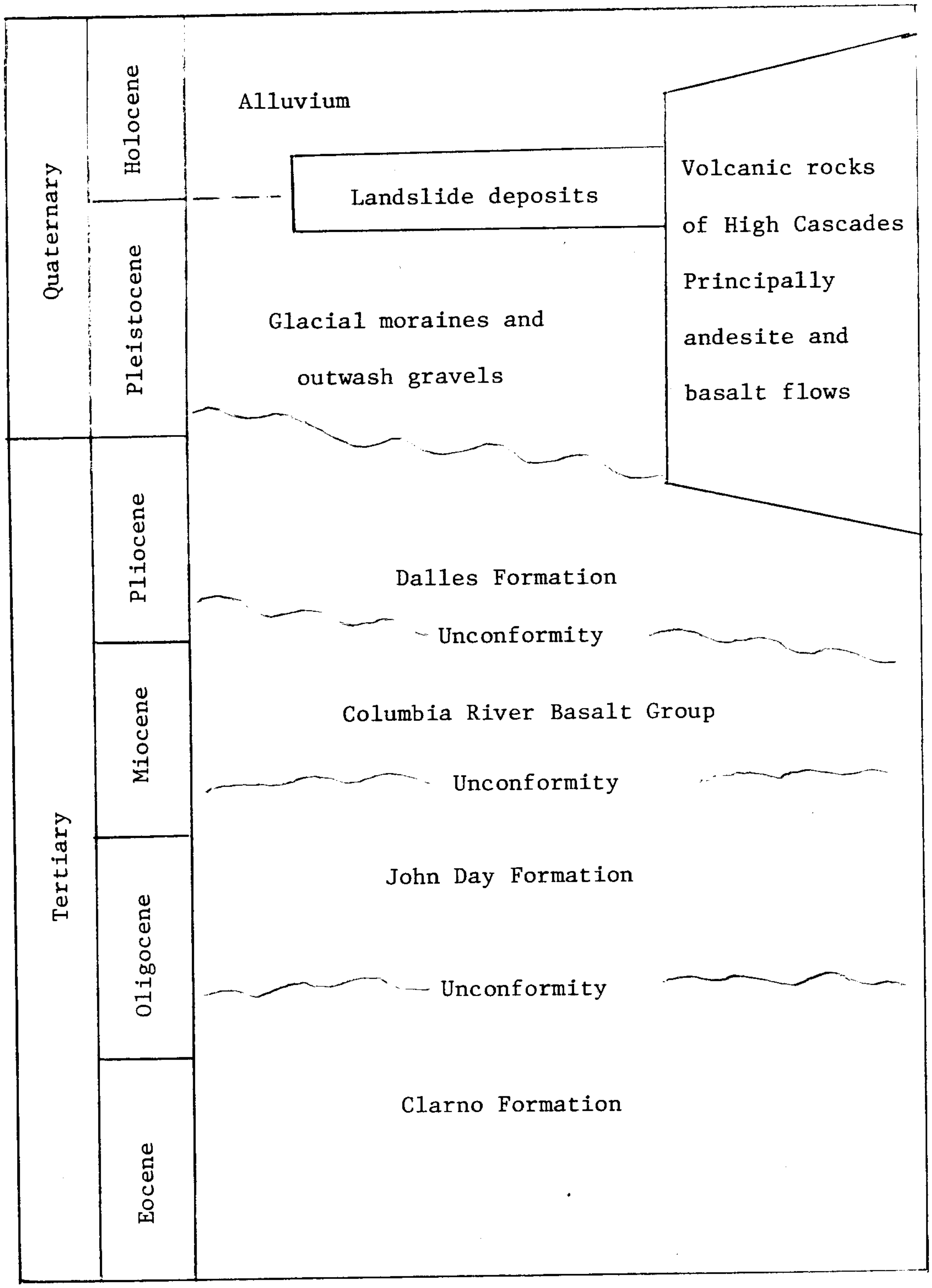


Figure 4. Major rock units of the Warm Springs Indian Reservation.